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(54) Title: METHOD AND SYSTEM FOR CONTROLLING A FLUID CATALYTIC CRACKER
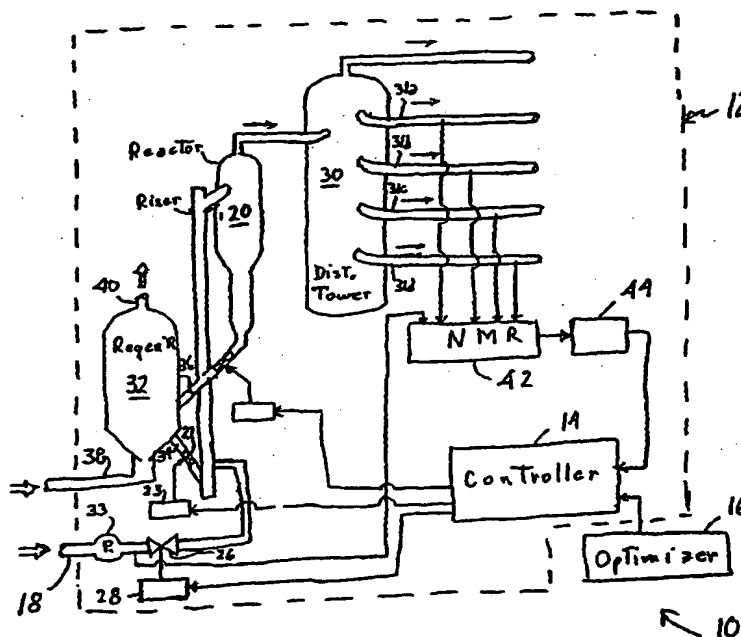
(57) Abstract: A method for controlling the output of a distillation tower fed by a fluid catalytic cracker uses one or more NMR sensors to obtain on-line measurements of values of selected properties of feedstock and/or of distillation tower outputs. The measured values are provided to a multivariate controller. On the basis of the measured values and setpoint information provided by an optimizer, the multivariate controller determines values of manipulated variables for controlling the catalytic cracker to produce products of desired qualities and maximize unit economic return.

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METHOD AND SYSTEM FOR CONTROLLING
A FLUID CATALYTIC CRACKER

BACKGROUND

5   This invention relates to the field of petroleum refining and in particular to methods and systems for controlling petroleum distillates produced in a distillation tower.

Crude oil, also known as petroleum, is a complex mixture of hydrocarbons. The component hydrocarbons are separated from one another to produce commercially valuable petroleum products. The various physical and chemical processing steps for separating

10   crude oil into component hydrocarbons are collectively referred to as "refining."

Because the component hydrocarbons differ in their volatility, an effective technique for separating them from one another is fractional distillation. In this technique, heated petroleum is placed in a distillation tower having a temperature gradient that progressively decreases from a high at the base of the tower to a low at the top of the tower.

15   Petroleum vapor, which consists of the component hydrocarbons in their vapor phase, rises through the distillation tower. As it rises, the petroleum vapor encounters progressively lower temperatures. When the petroleum vapor reaches a height at which the temperature in the distillation tower is equal to the condensation temperature of one of the vapor's components, that component condenses. A tray placed at that level of the tower collects that

20   condensed hydrocarbon component.

The relative amounts of each petroleum fraction generated in the distillation tower depend, to a great extent, on the composition of the petroleum. A refiner's control of the composition of any particular variety of petroleum to be processed is limited. Refiners must often process equity crudes or those available on an attractive commercial basis from

25   the short term or spot markets. Therefore, there is limited ability to regulate the yields of different petroleum fractions generated by distillation. In addition, demands for light, clean petroleum products normally exceed the quantity of these products appearing naturally in crude oils which are recoverable by distillation only.

At the dawn of the petroleum refining industry, the scarcity of electric lighting made

30   clean-burning lamp oils such as kerosene the petroleum fraction in highest demand. However, with the advent of the internal combustion engine, the demand for lighter petroleum fractions, such as gasoline, increased significantly at the expense of heavier petroleum fractions, such as kerosene. In response, the petroleum refining industry has

developed methods for increasing the gasoline yield obtained from a particular variety of petroleum. Catalytic cracking is one such method.

In catalytic cracking, a petroleum fraction heavier than gasoline, commonly called gasoil, is fed into a reaction chamber and vaporized into a hydrocarbon vapor at an

5   extremely high temperature. Ceramic pellets containing catalytic agents are introduced into the hydrocarbon vapor. A high velocity vapor stream propels the ceramic catalyst pellets into the reaction chamber and disperses them throughout the hydrocarbon vapor. The catalyst carried by the pellets facilitates a chemical reaction in which the hydrocarbon molecules split, or "crack," into lighter molecules. These lighter molecules pass to a

10 distillation tower called the main fractionator for recovery. Because the vapor now contains lighter hydrocarbon molecules, distillation of the vapor yields additional gasoline and other light hydrocarbons.

The extent to which hydrocarbon vapor is cracked into lighter molecules depends, in part, on the hydrocarbon composition supplied to the reaction chamber and on the rate at

15 which it is supplied.

In conventional methods for controlling the operation of a catalytic cracker, measurements of the gasoil composition and products from the main fractionator are obtained by periodically sampling the feed and product streams, and testing the samples in a laboratory. This, however, is costly and time-consuming. As a result, it is difficult to

20 perform laboratory testing frequently enough to attain up-to-date values of selected quality properties of the feedstock and all the distillates which the cracked hydrocarbon mixture yields. Consequently, this known method results in poor control over the catalytic cracking process.

25 SUMMARY

The method of the invention overcomes deficiencies in the art by performing on-line measurements of the values of selected properties of one or more hydrocarbon materials involved in the catalytic process. In one instance, these are materials fed to the catalytic cracker, i.e. the input feedstock. In another instance, these materials involved in the

30 catalytic process are at least one output fraction from the main fractionator tower fed by a fluid catalytic cracker. The results of these on-line measurements, together with the desired values of the selected properties of the materials being measured, are provided to an

automated controller. On the basis of these measurements, the controller calculates values of manipulated process variables to apply to the fluid catalytic cracker to obtain output fractions having the desired values of the selected properties. Because the estimates are performed on-line, a system incorporating the invention responds rapidly to variations in

5   the measured materials.

In most practices of the invention, it is deemed preferable to secure both gasoil feedstock measurements and output product measurements, and to manipulate process variables in response to both groups of measurements. However, features of the invention may extend to practices where only the gasoil feedstock is measured, or where

10   only one or more output fractions are measured, and one or more manipulated process variables are adjusted in response to such measurement. The process variables are adjusted for feed-forward control in response to measurements of gasoil feedstock material, and are adjusted for feed-back control in response to measurements of product material.

A preferred practice of the invention employs nuclear magnetic resonance

15   measurements in conjunction with values of selected material properties, e.g. of the gasoil feedstock or of one or more product fractions. NMR measurements do not rely on optical or infrared radiation, and are therefore not affected by high opacity. Additionally, NMR measurements are relatively stable as a function of temperature. Consequently, reliable measurements can be made across the broad range of temperatures of the gasoil feedstock

20   and of the various product fractions produced in the main fractionator.

One illustrative practice of the invention includes the steps of imposing a steady magnetic field on a material involved in the catalytic process, for example on a sample of a hydrocarbon output fraction. With the steady magnetic field in place, a nuclear magnetic resonance (NMR) sensor imposes a transient magnetic field on the fraction and measures its

25   response to the transient magnetic field. An NMR sensor generally does not directly provide values of the selected properties of the fraction. Instead, the NMR sensor provides the chemical composition of the fraction. For this reason, the method of the invention includes the step of ascertaining values of the properties of the measured material on the basis of its measured composition. These values are then used to selectively control

30   process variables such as the gasoil flow rate into the fluid catalytic cracker, the regenerator catalyst slide valve position, reactor dense bed level, regenerator pressure, feed preheat temperature, air or oxygen injection rate, reactor/regenerator differential pressure, wet gas

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compressor suction pressure, main fractionator product draw rates, steam injection rates, overhead reflux duty, overhead accumulator release, and slurry to steam generators, thereby generating a product fraction having desired values of selected quality properties. The exact set of process variables available for manipulation will depend upon the specific

5   configuration of the individual fluid catalytic cracking unit. Examples of these selected quality properties include aromaticity, boiling point, flash point, cloud point, viscosity, pour point, API gravity, freeze point, octane, PIONA, RVP, and other chemical or physical properties.

The information obtained from the NMR measurements can, in accord with the

10   invention, be used to explicitly control both the conversion in a fluidized catalytic cracking unit, and the selectivity of the unit to the desired levels. This practice of the invention involves NMR measurements on materials directly involved in the catalytic conversion, and are made on-line and essentially in real time.

The desired product qualities are generally dictated by competitive market forces,

15   environmental regulations and economic factors including feed and product prices and operating costs. They may also be constrained by specific characteristics of the refinery including equipment configuration and availability and operating constraints.

The method of the invention can thus provide real-time measurements of the values of selected properties of gasoil feed and of a variety of fractions produced by the main

20   fractionator. These real-time measurements enable the control system of the invention promptly to adjust the operation of the catalytic cracker to compensate for fluctuation in the feedstock and/or in the output of the main fractionator. Because the method of the invention relies on NMR rather than on optical techniques, the accuracy of these measurements can be essentially independent of the opacity or the temperature of the

25   measured material.

A system for practice of the invention includes an optimizer for specifying desired long-term values of selected fluid catalytic cracker operating variables that produce products of the desired qualities while optimizing economic operation of the unit considering among other things feed and operating cost and product values. The optimizer

30   also takes into account specific characteristics of the refinery including equipment configuration and availability and operating constraints including product production limits.

A system for practice of the invention further includes a sensor for estimating the values of selected product properties. These estimates, together with the desired long term values of selected operating variables specified by the optimizer, are provided to a controller. On the basis of the values from the sensor, desired product properties values and

5   the long-term desired values from the optimizer, the controller determines current values of the operating variables needed to form products having the desired values of the selected properties, while optimizing economic performance of the refinery, and in particular of the catalytic cracker.

Practice of the invention also includes measuring, with nuclear magnetic resonance,

10   parameters regarding the composition of at least one material or substance directly involved in a catalytic converter in a petrochemical process, and applying the measured information to a controller of the petrochemical process. The measured material or substance can be the feedstock, or an ingredient of the feedstock, and can be one or more petrochemical product fractions. A preferred practice performs both feedstock and product measurements. The

15   controller determines, in response to the measured information and to further target information it stores or receives regarding desired parameters of the petrochemical process, including of materials produced or otherwise involved, control signals for adjusting the process to attain selected values of the measured information relative to the target information.

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DESCRIPTION OF THE FIGURES

These and other features and advantages of the invention will be apparent from the following detailed description and the accompanying figures, in which:

FIG. 1 is a schematic block drawing of a multivariate distillation control system

25   embodying features of the invention;

FIG. 2 is a schematic block drawing showing details of the distillation system of FIG. 1; and

FIG. 3 is a schematic block drawing of another distillation system according to the invention.

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DESCRIPTION OF ILLUSTRATED EMBODMENTS

FIG. 1 shows a multivariate control system 10 incorporating principles of the invention. The multivariate control system 10 includes a petrochemical cracking system 12 that receives an input feedstock and that is in communication signal-wise with a multivariate controller 14. The output product of the cracking system 12 includes a plurality of hydrocarbon products each characterized by values of selected properties. These values, which are represented in FIG. 1 by an output vector y that is fed back to the multivariate controller 14, are controlled variables for the multivariate control system 10.

The effectiveness of the illustrated controller 14 is enhanced by also applying to it an input vector z representing values of selected properties that characterize the input gasoil feedstock. The multivariate control system 10 includes an optimizer 16 for generating desired long-term values of selected operating variables that produce the desired product qualities, while optimizing economic operation . These desired values are represented in FIG. 1 by a setpoint vector r generated by the optimizer 16 and supplied to the multivariate controller 14. The elements of vector r are specified taking into account feed and operating cost, product economic values, and specific characteristics of the refinery including equipment configuration and availability and operating constraints including product production limits.

In response to the set-point vector r and one or more differences between desired product qualities and the output vector y and/or changes in feedstock vector z, the multivariate controller 14 generates a vector of manipulated variables x that, when applied to the cracking system 12, adjusts the cracking system operation to change the values of the elements in the output vector y to approach the corresponding desired values.

FIG. 2 shows that the illustrated cracking system 12 includes an input pipeline 18 leading to a reaction chamber 20. A pump 33 coupled to the input pipeline 18 propels a gasoil feedstock mixture into the reaction chamber 20 through a control valve 26 that is opened and shut by a valve actuator 28 under the control of the multivariate controller 14. The reaction chamber 20 is also in fluid communication with a regeneration chamber 32 by means of a catalyst feed pipe 34 and a catalyst removal pipe 36. This regeneration chamber 32 has an air or oxygen intake 38 and an exhaust 40 for use with the catalyst regeneration process. A control valve 22 in the catalyst feed pipe 34 is controlled by an actuator 23 that responds to input control signals from the controller 14. Hot regenerated ceramic catalyst

particles from the regeneration chamber 32 are added, by way of the catalyst feed pipe 34, to the gasoil feedstock in the riser prior to delivery to the reactor chamber 20. The heat from the catalyst particles causes the gasoil feedstock to vaporize and the resultant high velocity vapor stream carries the catalyst particles into the reactor chamber 20.

5   The reaction chamber 20 is in fluid communication with the main fractionator tower 30 of the type commonly found in petroleum refineries. Such a distillation tower 30 typically includes a plurality of tower outputs 31 located at different heights along the tower 30. Each output corresponds to a particular fraction distilled from the petroleum input. Outputs located at the lower portions of the tower 30 correspond to heavier fractions, such

10   as heating oil or kerosene. Outputs located at the higher portions of the tower 30 correspond to lighter fractions, such as gasoline or naphtha . The number of tower outputs affects the computational burden sustained by the multivariate controller 14, and is not the subject matter of the invention. Hence, for the sake of clarity and ease of exposition. FIG. 2 shows only four tower outputs 31a-d.

15   A nuclear magnetic resonance (NMR) sensor 42 is coupled to various selected stages of the cracking system 12 to measure chemical properties of material at those selected stages in the process. The illustrated sensor 42 of FIG. 2 is coupled to the input pipeline 18 to sample the feedstock, and is coupled to each tower output 31a-d to sample each product, or fraction, produced by the main fractionator tower 30. Although the

20   cracking system 12 shown in Figure 2 has a single NMR sensor 42 responding, for example, on a time-shared basis to each of multiple inputs, it will be understood that one or more additional NMR sensors can be provided to respond to the sampled materials. The sensed information output from the NMR sensor 42 is applied to a calibrator 44 that transforms it to a format suitable for the multivariate controller 14.

25   One preferred sensor employs the technology of the I/A Series® Process NMR equipment available from The Foxboro Company of Foxboro, Massachusetts, however, a wide variety of NMR sensors may be used for chemical analysis.

          A suitable calibrator is preferably a chemometic modeling unit. A chemometic modeling unit for the calibrator 44 and suitable for practice of the invention is implemented

30   by a digital processor executing instructions for estimating values of selected physical properties on the basis of the measured chemistry of a sample, as determined by an NMR sensor. These instructions implement procedures that are well-known to those of ordinary

skill in the art. Such procedures include establishing look-up tables, interpolating between values in a look-up table, and implementing mathematical models for estimating values of the selected properties. FIG. 3 shows the calibrator 44 as a separate element for clarity, however, the calibrator 44 may be integrated into software anywhere in the system.

5   Both the optimizer 16 and the multivariate controller 14 are preferably implemented as software instructions executed on a programmable digital processor. In one practice, these instructions are executed on a general purpose digital computer. However, particularly to meet demanding performance requirements, the optimizer 16 and the multivariate controller 14 can be implemented in hardware, for example, with application

10   specific integrated circuits, in software, or in a combination of hardware and software. A suitable optimizer and multivariate controller for practice of the invention are sold by Simulation Sciences of Brea, California, USA under the trade designations ROMeo™ and Connoisseur™, respectively. The specific implementation details of the multivariate controller 14 and the optimizer 16 are within the purview of one of ordinary skill in the art

15   and do not affect the scope of this invention.

In operation of the system shown in FIGS. 1 and 2, the pump 33 propels gasoil feedstock through the control valve 26 and into the reaction chamber 20. At the same time, small hot pellets of catalyst material are added through the catalyst feed pipe 34 and the slide valve 22, from the regeneration chamber 32. The heat from the catalyst particles

20   causes the gasoil feedstock to vaporize and the resultant high velocity vapor stream propels the catalyst particles into the reaction chamber 20. The catalyst is typically a ceramic material, such as zeolyte. However, other catalysts are known and used in connection with fluid catalytic cracking. The presence of the catalyst within the reaction chamber 20 facilitates breaking the covalent bonds of the molecules in the gasoil mixture to produce

25   lower molecular weight hydrocarbons.

Heat is produced by burning carbon off catalyst in the regenerator 32. This heat is transferred to the reactor via the catalyst feed pipe 34 to heat the gasoil feed to sufficient temperature to catalytically crack the gasoil to lighter molecules. This results in the generation of a vaporous mixture of numerous hydrocarbon species having generally lower

30   molecular weights than the hydrocarbon species present in the feedstock. This vaporous mixture of low molecular weight hydrocarbons flows into the main fractionator 30 for

separation into a plurality of products. These products exit the main fractionator 30 through a plurality of tower outputs, four of which are shown in FIG. 2.

A byproduct of the cracking process is the deposition of carbon on the catalyst pellets. These carbon deposits suppress the interaction between the catalyst and the gasoil

5   vapor, thereby reducing the effectiveness of the catalyst. As a result, catalyst pellets are continuously drawn off the reaction chamber 20, blown through the catalyst removal pipe 36, and returned to the regeneration chamber 32. Air or oxygen from the intake 38 is injected to burn carbon off the catalyst pellets to renew catalytic activity and to generate heat to sustain the cracking process. The gaseous byproducts of this regeneration process

10   are vented from the regeneration chamber through the exhaust 40.

As noted above, the illustrated NMR sensor samples the feedstock and samples the products from the main fractionator 30. The NMR sensor 42 imposes a steady magnetic field on each such sample to align the magnetic dipole moments associated with the molecules in the sample. With the steady magnetic field in place, the NMR sensor 42

15   imposes a transient magnetic field having a direction different from, and preferably orthogonal to, that of the steady magnetic field. This transient magnetic field temporarily aligns the dipoles from the sample in a direction other than that in which the static magnetic field aligns dipoles. When the transient magnetic field is turned off, the dipoles in the sample spring back into the alignment imposed upon them by the steady magnetic field. As

20   they do so, the dipoles generate a RF signal. The rate at which a particular dipole springs back to alignment with the steady magnetic field, and hence the frequency of the resulting RF signal, is characteristic of the sample's molecular structure. The resultant RF spectrum is responsive to, and hence provides a way of determining, the chemical composition of the sample.

25   The NMR sensor thus provides information on the chemical composition of materials or substances directly involved in the process stream of the cracking system 12. As illustrated, these include the feedstock and the fractions formed in the main fractionator 30. It is known in the art to predict the corresponding values of selected properties from this measured composition of the sample. This operation of converting the measured sample

30   composition to values of selected properties is carried out, in the embodiment of FIG. 2, by a calibrator 44 in communication with both the multivariate controller 14 and the NMR sensor 42. The input information to the calibrator 44 includes the chemical composition of

the samples as measured by the NMR sensor 42. The output of the calibrator 44 is a corresponding set of measured values of the selected properties for each measured sample. These selected properties can include aromaticity, boiling point, flash point, cloud point, viscosity, pour point, API gravity, freeze point, octane, PIONA, RVP, or other chemical or

5   physical properties.

        In response to the data provided by the NMR sensor 42, together with other conventional data, as from other sensors (not shown) of level, pressure, pressure differential, temperature, time, and flow rate as conventional and known in the art, the multivariate controller 14 determines values of the manipulated variables which minimize

10   the difference between the desired values of the product qualities and the values of the corresponding selected product qualities, as provided by the NMR sensor 42. Desired long-term values of the operating variables as determined by the optimizer 16 are also taken into account by the controller 14. The controller 14 determines the values of the manipulated variables using methods known in the art. These methods include the use of a look-up table

15   and the implementation of empirically derived mathematical models. These manipulated variables include the flow rate of gasoil feed into the reaction chamber, regenerator catalyst slide valve position, reactor dense bed level, regenerator pressure, feed preheat temperature, air or oxygen injection rate, reactor/regenerator differential pressure, wet gas compressor suction pressure, main fractionator product draw rates, steam injection rates, overhead

20   reflux duty, overhead accumulator release, and slurry to steam generation. The exact set of process variables available for manipulation will depend upon the specific configuration of the individual fluid catalytic cranking unit.

        Having determined the values of the manipulated variables, the multivariate controller 14 transmits control signals to the actuator 28 to marginally open or close the

25   control valve 26 to adjust the flow rate of the gasoil feed into the reaction chamber 20. Similar signals are sent to control the other manipulated variables.

        Because the NMR sensor 42 and the calibrator 44 rapidly provide information concerning the process stream to the multivariate controller 14, the controller 14 will readily respond to fluctuations in properties of the feedstock and of the distillates. This

30   enables the controller 14 to change the settings associated with the catalytic cracking process to reduce any difference between measured properties and corresponding desired properties.

FIG. 3 shows an NMR stage 42' that can be used in the system of FIG. 2 in place of the NMR 42 of that drawing. The illustrated NMR stage 42' has a set of multiple NMR sensors 42a, 42a, each connected to receive information regarding the different product sample. The inputs to each NMR sensor 42a, 42a, can be a separate tower output 31a,

5   31b... of FIG. 2. The output signals from the NMR sensors are applied to an interface selector 42b that operates in conjunction with the multivariate controller 14 of FIG. 2. The illustrated interface selector 42b applies the output from any selected one NMR sensor 42a to a calibrator 44, typically the calibrator 44 of FIG. 2.

As also shown in FIG. 3, the illustrated NMR stage 42' has a further NMR sensor

10   42c, the output of which is applied to the input selector 42b. The illustrated NMR sensor 42c receives information from either of two feedstock samples, by way of sample lines 43a and 43b and a controllable selector 42d. The two input lines 43a and 43b illustrate for purposes of example only, that the invention can be practiced both with measured information from multiple products and with information from multiple feedstock samples.

15   The illustrated NMR stage 42' further illustrates that the invention can be practiced with one or more NMR sensors that receive information from a single sample or from any of two or more material samples, depending on the optimum instrumentation strategy for a particular petrochemical conversion facility.

The system configurations described above illustrate the chemical cracking

20   techniques described herein. However, a wide variety of other configurations can also take advantage of these techniques.

Having described the invention, and a preferred embodiment thereof, what is claimed as new and secured by Letters Patent is:

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1. A method for controlling a petrochemical cracking system having a distillation tower fed by a catalytic converter, said method comprising the steps of:

performing an on-line NMR measurement of at least one material that the cracking system processes to ascertain measured values of selected properties of that

5   measured material,

specifying desired values of said selected properties of the measured material, and

determining, on the basis of said measured values of said selected properties, values of manipulated variables of the cracking system for controlling selected properties of

10   at least one output fraction from the distillation tower.

2. A method according to claim 1 wherein said step of determining values of manipulated variables includes determining values of manipulated variables that explicitly control both the conversion in the cracking system and the selectivity of the system to

15   desired values.

3. A method according to claim 1

wherein said step of performing an NMR measurement measures at least a feedstock material of the cracking system, and

20   wherein said determining step determines values of manipulated variables for at least feed-forward control of the cracking system.

4. A method according to claim 1

wherein said step of performing an NMR measurement measures at least an

25   output product material of the cracking system, and

wherein said determining step determines values of manipulated variables for at least feed-back control of the cracking system.

5. Apparatus for controlling a petrochemical cracking system having a distillation

30   tower fed by a catalytic converter, said apparatus comprising

an NMR sensor configured to measure properties of at least one material that the cracking system processes, and

a multivariate controller in communication with said NMR sensor, said multivariate controller generating, on the basis of measurement-responsive information supplied by said NMR sensor, control signals for adjusting the operation of the cracking system to obtain desired values of selected properties of at least one output fraction.

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6. Apparatus according to claim 5 wherein
said NMR sensor measures properties of at least one feedstock material of the cracking system, and
wherein said controller generates control signals at least for feed-forward
10   control of the cracking system.

7. Apparatus according to claim 5 wherein
said NMR sensor measures properties of at least one output product material of the cracking system, and
15   wherein said controller generates control signals at least for feed-back control of the cracking system.

8. A method for controlling a petrochemical process having a catalytic converter for producing a petrochemical fraction, said process including the steps of
20   performing an on-line NMR measurement of parameters regarding the composition of at least one feedstock material input to the petrochemical process,
performing an on-line NMR measurement of parameters regarding the composition of at least one petrochemical fraction produced with the catalytic converter,
applying the measured information to a controller of the petrochemical
25   process,
applying to the controller target information identifying desired parameters of at least one fraction of the petrochemical process, and
producing with the controller, in response to the measured information and the target information, control signals for adjusting the process to attain a selected value of
30   the measured information relative to the target information.

9. A method for controlling at least one output fraction of a distillation tower fed by a catalytic converter, said method comprising the steps of

performing at least any one of (i) an on-line NMR measurement of the petrochemical feedstock to ascertain measured values of selected properties of the

5   feedstock, and (ii) an on-line NMR measurement of at least one output fraction to ascertain measured values of selected properties of said at least one output fraction,

specifying desired values of said selected properties of said at least one output fraction, and

determining, on the basis of said measured values of said selected properties,

10   values of manipulated variables for controlling said measured values of said selected properties of said at least one output fraction.

10. The method of claim 9 wherein said step of performing an on-line NMR measurement comprises the steps of

15   imposing a steady magnetic field on material to be measured, superimposing a transient magnetic field on said steady magnetic field, and measuring a response of the measured material to said transient magnetic field.

11. The method of claim 9 wherein said selected properties are selected from a

20   group consisting of aromaticity, boiling point, flash point, cloud point, viscosity, pour point, API gravity, freeze point, octane, PIONA, and RVP.

12. The method of claim 9 further comprising the step of specifying catalytic cracking unit operating conditions on the basis of economic conditions.

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13. The method of claim 9 further comprising the step of selecting said manipulated variables to include at least one of the following: the flow rate of a feed to said fluid catalytic converter, the regenerator catalyst slide valve position, reactor dense bed level, regenerator pressure, feed preheat temperature, air or oxygen injection rate,

30   reactor/regenerator differential pressure, wet gas compressor suction pressure, main fractionator product draw rates, steam injection rates, overhead reflux duty, overhead accumulator release, and slurry to steam generators.

14. The method of claim 9 further comprising the step of selecting said manipulated variables to include a temperature range at which said output fraction is formed.

5   15. An apparatus for controlling at least one output fraction of a distillation tower fed by a catalytic converter in a processing system, said apparatus comprising

an NMR sensor configured to measure properties of at least one of (i) a petrochemical feedstock to the system and (ii) at least one output fraction, and

a multivariate controller in communication with said NMR sensor, said
10   multivariate controller generating, on the basis of measurement-responsive information supplied by said NMR sensor, control signals for adjusting the operation of the processing system to obtain desired values of selected properties of at least one output fraction of the system.

15   16. The apparatus of claim 15, wherein the multivariate controller receives one or more set-point values from an optimizer.

17. The apparatus of claim 16, wherein the one or more set-point values comprise values determined on the basis of at least one of the following: feed cost, operating cost,
20   product production limits, and refinery equipment configuration.

18. A system for processing petrochemicals, the system comprising:

a petrochemical cracking system, the system having at least one input pipeline for receiving gasoil feedstock and at least one output for distillates produced by
25   catalytic cracking of the received feedstock;

a feedback control loop for controlling the petrochemical cracking system, the feedback control loop receiving signals from at least one NMR sensor configured to measure at least one output fraction, the feedback control loop adjusting the petrochemical cracking system based on at least measurement of the NMR sensor.

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19. The system of claim 18, wherein the feedback control loop controls the petrochemical cracking system by specifying at least one of the following parameters: flow rate of hydrocarbon vapor into the reaction chamber, regenerator catalyst slide valve position, reactor dense bed level, regenerator pressure, feed preheat temperature,

5   air or oxygen injection rate, reactor/regenerator differential pressure, wet gas compressor suction pressure, main fractionator product draw rates, steam injection rates, overhead reflux duty, overhead accumulator release, and slurry to steam generation.

20. The system of claim 18, wherein the petrochemical cracking system comprises

10   a distillation tower fed by a catalytic converter.

21. The system of claim 18,
        further comprising at least one NMR sensor configured to measure at least one property of the gasoil feedstock; and

15   wherein the feedback control loop comprises a feedback control loop for adjusting the petrochemical cracking system based on at least one NMR sensor measurement of the input feedstock.
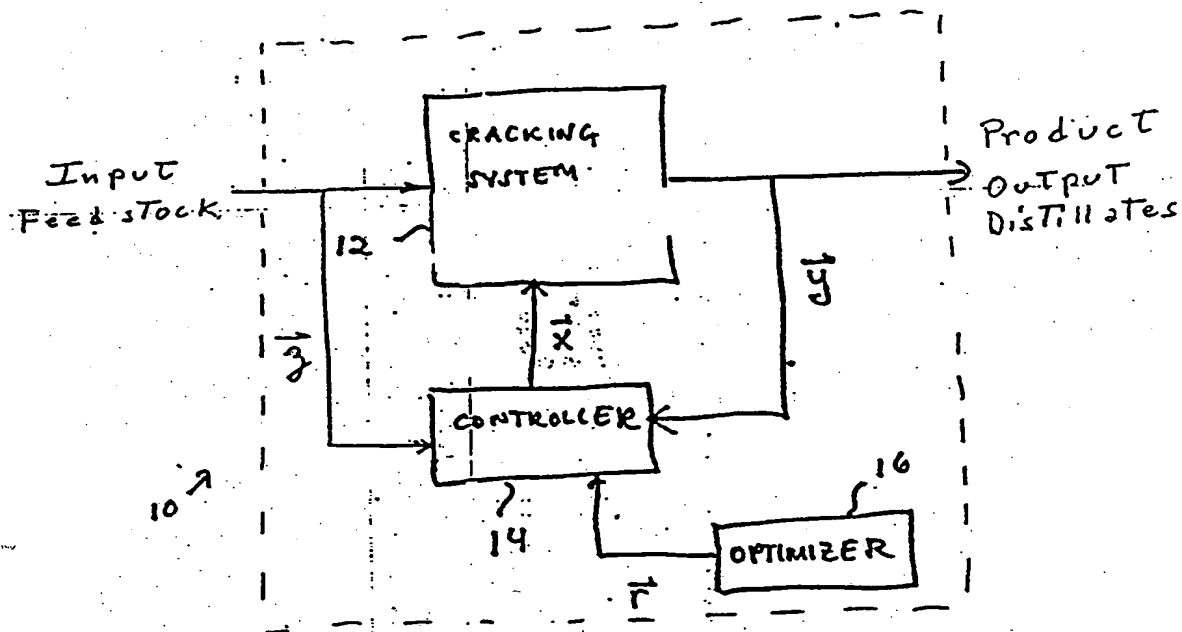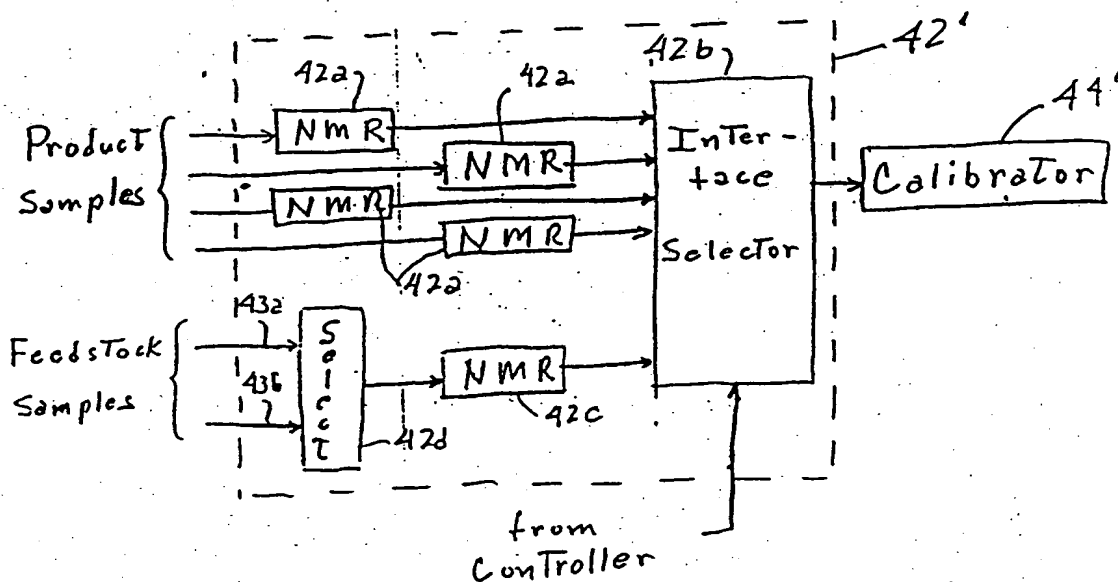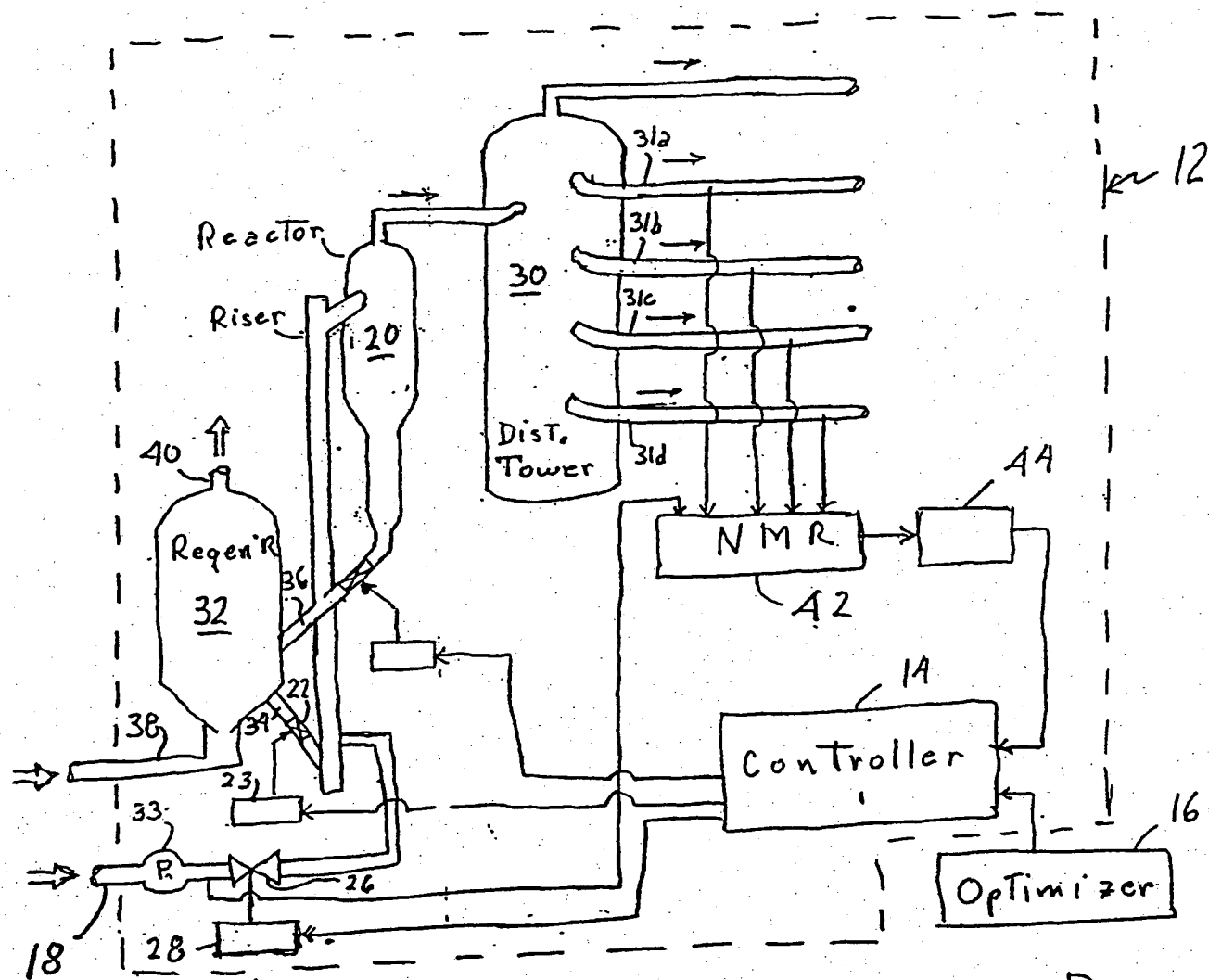
FIG. 1

FIG. 3

FIG. 2

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   C10G11/18   B01J8/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7   C10G   B01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and. where practical, search terms used)

WPI Data, PAJ, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 437 977 A (GARY FUNK) 20 March 1984 (1984-03-20)	
A	US 5 580 531 A (DASSEL MARK WILLIAM ET AL) 3 December 1996 (1996-12-03)	

☐ Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 April 2001	20/04/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Michiels, P

Form PCT/ISA/210 (second sheet) (July 1992)

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 4437977	A	20-03-1984	NONE		
US 5580531	A	03-12-1996	AU	5752296 A	30-12-1996
			BR	9609096 A	10-08-1999
			CA	2224177 A	19-12-1996
			CN	1190950 A	19-08-1998
			EP	0837842 A	29-04-1998
			WO	9640610 A	19-12-1996

CORRECTED VERSION

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(74) Agents: LIEPMANN, W., Hugo et al.; Foley, Hoag & Eliot, LLP, One Post Office Square, Boston, MA 02109-2170 (US).
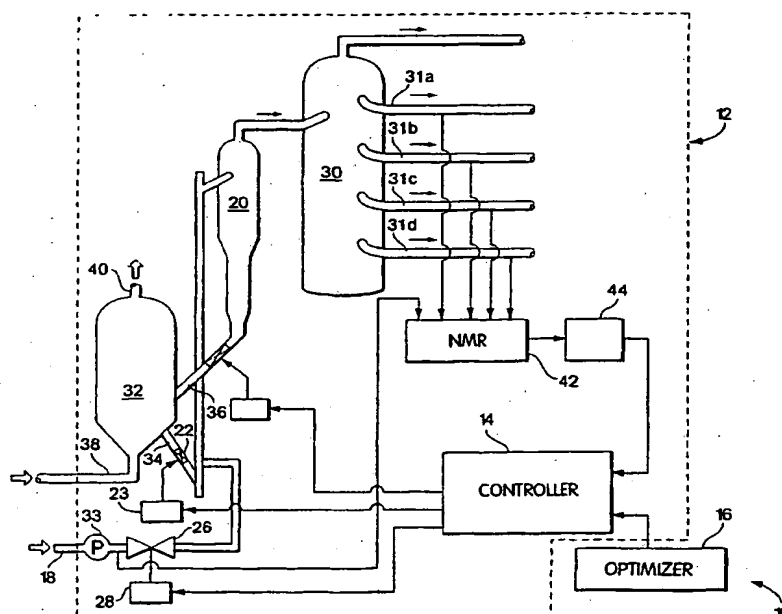
(81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European

(54) Title: METHOD AND SYSTEM FOR CONTROLLING A FLUID CATALYTIC CRACKER

(57) Abstract: A method for controlling the output of a distillation tower fed by a fluid catalytic cracker uses one or more NMR sensors to obtain on-line measurements of values of selected properties of feedstock and/or of distillation tower outputs. The measured values are provided to a multivariate controller. On the basis of the measured values and setpoint information provided by an optimizer, the multivariate controller determines values of manipulated variables for controlling the catalytic cracker to produce products of desired qualities and maximize unit economic return.